Dynamic Effects of Communication in Software Development Teams: A Comparison of Three Models

Jun He
University of Michigan - Dearborn, junhe@umd.umich.edu

Follow this and additional works at: http://aisel.aisnet.org/amcis2008

Recommended Citation
http://aisel.aisnet.org/amcis2008/109

This material is brought to you by the Americas Conference on Information Systems (AMCIS) at AIS Electronic Library (AISeL). It has been accepted for inclusion in AMCIS 2008 Proceedings by an authorized administrator of AIS Electronic Library (AISeL). For more information, please contact elibrary@aisnet.org.
Dynamic Effects of Communication in Software Development Teams: A Comparison of Three Models

Jun He
University of Michigan - Dearborn
junhe@umd.umich.edu

ABSTRACT
Communication is essential to the performance of software development teams. But assuming the effect of communication on team performance to be linearly positive has been questioned in the literature. Based on team development theory and team cognition theory, this study contends that the effect of communication is dynamic and contingent on team progress. To assess the dynamic effects of communication, a longitudinal study was conducted of 73 student software development teams. Three models of communication were tested: linear model, time model, and team cognition model. The results revealed that different communication methods (emails, calls, and meetings) presented systematically changing effects on team performance as team progressed. The frequencies of emails and meetings presented increasing effects, while the frequency of telephone calls presented a decreasing effect, on team performance with time passage and the development of team cognition. An optimal model emerged from the testing results. Implications for systems development researchers and practitioners are also discussed.

Keywords
Team communication, communication frequency, team cognition, team performance, longitudinal study, time analysis.

INTRODUCTION
In the study of team performance, communication has been described as the “heart of group behavior” (Shaw 1981) and been considered as the primary means for team members to work together toward performance ends. It is through communication that team members interact with each other, share views and concerns, clarify team roles, assign sub-tasks, and coordinate their activities (Weisband, 2002). The essentiality of communication to team performance has been evidenced in different types of teams, including aviation crew (Foushee and Manos, 1981; Kanki and Foushee, 1989), R&D teams (Katz and Tushman, 1979), health-care program development teams (Pinto and Pinto, 1990), top management teams (Ancona and Caldwell, 1992), and software development teams (Brodbeck, 2001). The effects of communication are also found to be affected by various contextual factors, such as task type, communication technology, and team size (Baltes et al., 2002). However, one of the pervasive influences, time, has rarely been investigated in communication research (Brown and Miller, 2000).

The influence of time is profound in work settings where decisions must be made with deadlines in mind (Brown and Miller, 2000). In research, however, time is one of the most elusive concepts related to work (Cooper and Rousseau, 2000) and “the researcher implicitly suggests that a change occurs over time, but does not explicitly discuss the role of time” (Saunders and Kim, 2007, p. iii). This is particularly true for the study of software development, an area in which “Gantt charts” and other tools of charting time have been widely used for managing projects and coordinating activities of involved parties (Yakura, 2002), and meeting schedule is accepted as a key criterion for judging team performance (Sarker and Sahay, 2004). Few studies have empirically investigated how time shapes communication effects during the process of software development.

The objective of this study was to explore the dynamic effects of communication in software development teams. The rest of the manuscript is organized as follows. First, the literature of software development was reviewed. Hypotheses of communication effects were formulated under three theoretical models. A longitudinal study using student software development teams was designed to investigate the effects of communication during the team lifecycle. After data collection and analysis, the manuscript ends up with a discussion of the findings and implications for research and practice.

THE DYNAMIC NATURE OF TEAM COMMUNICATION IN SOFTWARE DEVELOPMENT
Software development projects are typically complex, dynamic, and involve unstructured tasks (Kraut and Streeter, 1995; Brodbeck, 2001; Xia and Lee, 2004). While much research attention has been placed on the arrangement of concrete tasks, for example, the four types of software development models including waterfall models, incremental models, evolutionary models, and agile models (Moløkken-Østvold & Jørgensen, 2005), empirical evidence demonstrates that behavioral factors have a stronger impact on team performance than the selection of software development tools and models does (Guinan et al.
1998). From a team development perspective, team members adapt their behaviors to the development process and approach work accordingly to meet with schedules. For example, at an initial stage of software development, team members often focus on social relationship building and negotiate team structures (e.g., the roles of members and the rules of teamwork) before working on concrete technical tasks. While in later stages when time pressure becomes more salient, team members have to get concrete technical tasks delivered quickly in order to meet the restricted schedule (Gersick 1989). Such a dynamic nature of team behaviors is robust across various team tasks (Wheelan, 1994; Wheelan and Hochberger, 1996).

Team communication is a key mechanism for software development project teams to coordinate members’ work (Mantei 1981; Hoegal and Gemuenden 2001). Communication effects on team performance are inevitably affected by team progress, which profoundly shapes team behavior along with time passage. Thus, understanding the changing effects of team communication to team performance has important implications to both software development researchers and practitioners. This study focuses on three common communication methods – emails, telephone calls, and face-to-face meetings – and their effects on the performance of software development teams during the development process. Three models were developed based on the traditional theory of team communication, the team development theory, and the team cognition theory. The latter two theories argue for dynamic effects of communication shaped by time and team cognition respectively.

THREE MODELS OF COMMUNICATION EFFECTS AND HYPOTHESES

Linear Model of Communication

Linear model of communication argues that communication has a linear and positive effect on team performance (Patrashkova-Volzdoska et al., 2003). Communication has long been studied as an important determinant for the success of software development teams (DeBrabander and Edstrom, 1977; Edstrom, 1977; Mantei, 1981; Kraut and Streeter, 1995). A common premise is that effective software development teams need to engage deeply in communication to exchange and share information among team members and to coordinate the execution of tasks in a harmonious fashion. The higher frequency of communication within a software development team, the better chance is expected for the team to achieve overall development success. The mostly employed communication model in the study of software development is linear model that assumes positive and linear effects of communication on team performance. However, linear model has been criticized as overly straightforward and fails to count on different situations that may shape the effects of communication (Patrashkova-Volzdoska et al., 2003).

Although the effectiveness of communication may be difficult to capture, the frequency of using different communication channels in a software development team can be readily detected and accurately assessed. Communication frequency reflects the quantity of messages conveyed through various modes within a certain period of time, therefore implies the intensity of knowledge activities and teamwork in software development teams. In team research, communication frequency has been widely used as an indicator for the intensity level of communications in teams, and is found to have profound impact on team performance (Pinto and Pinto, 1990; Smith et al., 1994).

\[ H1: \text{ Communication frequency is positively associated with team performance in software development teams. } \]

\[ H1a: \text{ The frequency of email communication is positively associated with team performance in software development teams. } \]

\[ H1b: \text{ The frequency of telephone communication is positively associated with team performance in software development teams. } \]

\[ H1c: \text{ The frequency of meetings is positively associated with team performance in software development teams. } \]

Time Model of Communication

Communication is dynamic in nature. Its pattern and effects are contingent on tasks and timelines (McGrath 1991). During the life-span of a software development project, “time … helps provide the organizing frame of reference for work groups through agendas, meeting schedules …” (Sarker and Sahay 2004, p. 5). Team members regulate their behaviors within time frameworks that are graphically constructed with Gantt charts or other time charting tools (Yakura 2002). In an exploratory study of virtual software development teams, Massey and colleagues (Massey et al 2003) analyzed temporal patterns of communication that emerged during the development process; these patterns were found to be associated with differential levels of performance, implying that communication takes a systematically changing effect on performance over time. Thus, teams who confine their communication behaviors to time demands will have a better chance to achieve quality performance.

The research of team development provides a solid theoretical ground for studying time effects in software development. Many team researchers agree that teams move through successive stages during the team lifecycle, each of the stages has different primary tasks and aims to achieve different objectives (Gersick 1988). A pioneer team development model was
proposed by Tuckman (1965) with four stages of “forming”, “storming,” “norming,” and “performing.” In another work, Wheelan (1994) synthesized a large body of team development work and proposed a model of five stages, including (1) dependency and inclusion, the first stage of team development in which team members initiate attempts to get to know each other and to determine what the rules, roles, and structures of this team will be; (2) counterdependency and fight, also termed as a conflict stage in which members begin to struggle with how the team will operate and what roles members will play; (3) trust and structure, a stage in which member relationships are well defined, and clear structures and roles emerge to facilitate effective teamwork; (4) work, the most productive stage, often triggered by an awareness of schedule (i.e., the time-bound frame); and (5) termination, the final phase in which termination issues (e.g., members evaluate their work and give feedback about each other and the team) dominate. Other stage models proposed in the literature have similar form and the differences, if exist, are due to the nature of the team’s task (Wheelan and Hochberger, 1996).

Some researchers take a different approach and view changes in team development as of punctuated equilibriums, leading to the proposition of team transition model (Gersick 1988, 1989). Team transition model argues that the urgency of deadlines helps teams alternate the inertia in team behaviors and themes through which they approach their work. As time passes, the awareness of deadline will alert team members the necessarily of adjusting their behaviors to assure the project being completed within schedule. If time for performing tasks is limited, teams will increase their task focus and reduce behaviors oriented toward fulfilling social functions (Kelly and McGrath, 1985). The increased attention to time especially around the midpoint of the total time allotted helps shift the focus of team behaviors to the execution of concrete tasks from supporting activities that are less-production-related (maintaining team well-being, finding different alternatives, etc.), inducing a “midpoint transition” in the team life span (Gersick 1989).

Both the team stage model and the team transition model agree that time regulates team behaviors by inducing team members to work more on concrete tasks and less on supporting activities as the deadline approaches. When communication activities are conducted largely for production needs, the frequency of communication becomes more relevant to the prediction of team performance. Thus, I hypothesize a moderating effect of time on the relationship between communication frequency and team performance.

\[ H2: \] Time moderates the relationship between communication frequency and team performance in software development teams in a fashion that communication frequency takes increasing effects over time. More specifically,

\[ H2a: \] The frequency of email communication takes an increasing effect on team performance over time.

\[ H2b: \] The frequency of telephone communication takes an increasing effect on team performance over time.

\[ H2c: \] The frequency of meetings takes an increasing effect on team performance over time.

**Team Cognition Model of Communication**

The recent development of team cognition provides a new theoretical lens to study the communication frequency - team performance relationship. Team cognition refers to the mental models collectively held by a group of individuals which enable them to accomplish tasks by acting as a coordinated unit (He et al 2007). Rather than studying observable activities among team members, team cognition addresses the underlying mental models that guide team behavior. As Walsh (1995) pointed out, team cognition functions as mental templates which are imposed on information environments to give them form and meaning, providing a cognitive foundation for action.

Execution of software development projects requires knowledge and expertise from many domains (Curtis, Krasner, & Iscoe, 1988) and different perspectives accommodating user, technical, and sociopolitical needs (Klein et al 2002). But the mere presence of individuals with diverse knowledge and skills is an insufficient condition for software development teams to achieve quality performance (Faraj and Sproull, 2000). The potential value of a team can only be realized if team members utilize their unique expertise in conjunction with the knowledge of other members (Nonaka and Takeuchi, 1995). Team cognition plays an important role in that it “allow(s) team members to draw on their own well-structured knowledge as a basis for selecting actions that are consistent and coordinated with those of their teammates” (Mathieu et al 2000, p. 274). Thus, team cognition help regulates team behavior toward performance ends. When team cognition is of high levels, team members share much understanding of one another’s knowledge and skills as well as the focal task (Liang et al 1995, Moreland 1999). With such understanding, team tasks are likely to be assigned to people who are most able to perform them (Hollingshead 1998, Moreland and Myaskovsky 2000), and coordination demands for communication are largely reduced (Vandenbosch and Higgins, 1996). For example, members of an experienced clinic operation team need not communicate much during a successful operation. On the other hand, the less frequent communication due to mature team cognition will be applied more to task executions than to other peripheral issues, resulting in an increased effect of communication frequency on team performance.
In summary, communication will be effective under mature team cognition. Thus, I hypothesize a moderating effect of team cognition on the relationship between communication frequency and team performance.

\textit{H3: Team cognition moderates the relationship between communication frequency and team performance in software development teams: the effect of communication frequency on team performance will be stronger when team cognition is of high levels than that when team cognition is of low levels.}

\textit{H3a: The effect of the frequency of email communication on team performance will be stronger when team cognition is of high levels than that when team cognition is of low levels.}

\textit{H3b: The effect of the frequency of telephone communication on team performance will be stronger when team cognition is of high levels than that when team cognition is of low levels.}

\textit{H3c: The effect of the frequency of meetings on team performance will be stronger when team cognition is of high levels than that when team cognition is of low levels.}

Team cognition model suggests that communication effects are contingent on the level of team cognition. Because team cognition develops and evolves over time (Mathieu et al. 2000; Levesque et al. 2001; He et al. 2007), the effect of communication frequency on team performance will change accordingly. Thus, team cognition model, although does not include the factor of time, implies that communication takes dynamic effects during the software development process.

**METHODS**

**Procedures**

A synthetic task of software development was designed to investigate the dynamic effects of communication during the lifecycle of software development teams. Synthetic tasks are “research tasks constructed by systematic abstraction from a corresponding real-world task” (Martin et al. 1998, p. 123). Performance on a synthetic task should exercise some of the same behavioral and cognitive skills associated with the real-world task, while avoiding the complexity (i.e., the existence of various confounding factors that may lower the opportunity of observing significant effects of the investigated factors) encountered in an uncontrolled field study on real tasks.

The synthetic task employed in this study was to develop a relational database system using Microsoft Access. The subjects were students. Except for team formation and task deadline, students were free to set their own schedules and procedures to carry out their tasks, simulating the software development process in a realistic manner.

227 undergraduates from two middle-eastern public universities participated in this study. The students enrolled in a similar information systems course and had a similar course requirement of collaboratively developing a relational database system over a 4-week period. The students were juniors (about 26%), seniors (about 64%), and fifth-year business majors (about 10%). When the project was assigned, students were instructed to form three-member teams and were allowed to make their own teammate selections. Some students selected acquaintances as teammates, while others chose students who happened to be seated nearby. 73 teams were formed with some variances in sizes (ranging from 2 to 5, with 3 as the dominant team size). The demographics of participants are reported in Table 1. The characteristics of teams are reported in table 2.

<table>
<thead>
<tr>
<th>Gender</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>103</td>
</tr>
<tr>
<td>Male</td>
<td>124</td>
</tr>
<tr>
<td>Total</td>
<td>227</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Major</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Accounting and Finance</td>
<td>100</td>
</tr>
<tr>
<td>Marketing</td>
<td>62</td>
</tr>
<tr>
<td>Management</td>
<td>65</td>
</tr>
<tr>
<td>Others</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>227</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Status</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Junior</td>
<td>59</td>
</tr>
<tr>
<td>Senior</td>
<td>145</td>
</tr>
<tr>
<td>Fifth Year</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>227</td>
</tr>
</tbody>
</table>

**Table 1. Demographics of Participants**
<table>
<thead>
<tr>
<th>Team Size</th>
<th>Single-Gender Teams</th>
<th>Mixed-Gender Teams</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>27</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>36</td>
<td>37</td>
<td>73</td>
</tr>
</tbody>
</table>

Table 2. Team Characteristics

Measures

This study investigates the moderating effects of time and team cognition on the communication frequency – team performance relationship. The involved measures are discussed below.

Communication Frequency

When working on their software development tasks, all student teams relied on three media for their communications: face-to-face meeting, telephone, and electronic mail. Following the work of Smith et al. (1994), I calculated the frequency of each medium used in teams during a specific time period. More specifically, communication frequencies were measured by the self-reported single-item instruments asking students for the numbers of meetings, calls, and emails that their teams had conducted during the prior week. Team level measures of communication frequency were constructed by averaging individual responses after aggregation analysis. These scores reflect the average frequency with which the team used a particular medium in a certain time period.

Team Cognition

Team cognition is measured by an 8-item instrument developed by He et al (2007). The 8 items includes 4 items originally developed by Faraj and Sproull (2000) regarding the shared awareness of expertise location (knowing who knows what) in the team, and 4 items adopted from Kraut and Streeter’s (1995) notion of shared task understanding (having a shared view of the software development project). The two sub-constructs were considered as two important elements of team cognition especially for software development teams (He et al. 2007). Because the employed testing method tests a model mainly at construct level (using sub-constructs will lead to severe problem of collinearity due to the much shared variances between sub-constructs), the average of the two-constructs would be calculated as an indicator of team cognition after concluding the validity of the construct discussed in a later section.

Team Performance

Team performance has been discussed in the literature as multidimensional (Faraj and Sproull 2000) and multistage (Wheelan and Hochberger 1996), interwoven with the different perspectives of stakeholders (DeLone and McLean, 1992; Linberg, 1999). There is no good general-purpose team performance measure that claims solid bases in theory and practice, and has passed thorough rigorous psychometric testing (Senior and Swailes 2004). This research focused on the dynamic effect of team communication, and the complicated nature of team performance was beyond the scope of the study. In this study I selected Robey et al.’s (1993) instrument for its special focus on software development and established validity in the literature (e.g., Jiang and Klein 2000, 2002; Wang et al 2006). Students were asked to use a 1-5 scale to rate the extent to which their teams operated efficiently, met the schedule, produced products with appropriate quantity and quality, and interacted effectively with people inside and outside the teams. After aggregation analysis individual responses were averaged to construct the final measure of team performance.

Control Variables

In this study I also included three other factors as control variables: team size, gender diversity, and knowledge of Access. Team size and gender diversity were measured objectively by analyzing the composition of each student team. Team size was measured by the number of members worked in a team; gender diversity used a dichotomous measure to depict the gender pattern of the team as of single-gender team (coded with 0) or mixed-gender team (coded with 1). Knowledge of Access was measured with one item asking students about their perceived knowledge on Access.

Data Collection, Analysis, and Results

Data Collection
During the software development process, students were asked to answer an online survey regarding their participation and team performance every week over a four week period. The first survey was conducted one week after the start of the project. Although encouraged by the course instructor, participating in the survey was voluntary. Students were told that the survey responses would not influence grades in any way. Some students failed to answer the survey on time, and some submitted incomplete answers. This resulted in 813 usable sets of individual data for analysis, or an 89.6% effective response rate.

The participated 73 teams generated a total of 296 team data points to assess team behaviors and performances at four time stages. To assure the data integrity of team-level representation, 13 team data were dropped because of less than 50% member participation. This resulted in 276 effective team-level data points for further analysis.

**Aggregation Analysis**

Before aggregating individual responses to the team level, it is necessary to confirm response homogeneity or agreement within each team. I selected three classes of statistic tests for the aggregation analysis: Inter-Rater Agreement (or $r_{WG(J)}$), Intraclass Correlation (or ICC), and Average Deviation Index (or AD). The three tests assess with different approaches the congruence among team members on their response to measured items. The $r_{WG(J)}$ index compares the observed within-group variances to an expected variance from random responding (James et al., 1984; 1993); the ICC index is based on a nested-ANOVA design and analyzes within-team and between-team variances (James, 1982); and the AD measures the absolute deviation of individual responses from group means regardless of response distribution (this feature makes AD an appropriate tool for aggregation analysis of open-end measures, such as communication frequencies used in this study) (Burke et al 1999). The use of different statistic tests provides methodological and statistical triangulation (Faraj and Sproull, 2000) and its conclusion is more rigorous.

The results of the aggregation analysis for each construct are reported in Table 3. The IRA values of two multi-item instruments – team cognition and team performance – were high ($r_{WG(J)}>0.7$ is often used as a heuristic for judging high vs. low within-group homogeneity (Cohen et al., 2001)), suggesting a satisfying level of homogeneity among responses within each team. In contrast, the ICC values are moderately acceptable (James, 1982) and are comparable to other similar studies (e.g., Faraj and Sproull, 2000). The AD values were much smaller than the mean values of the associated measures, suggesting that the absolute values of individuals’ responses deviated little from group means (Burke et al 1999). The calculation of three indices suggests a reasonable level of agreement within all the teams. As such, aggregating individual responses to the team level is justified.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Cronbach α</th>
<th>Aggregation Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team Size</td>
<td>0.92</td>
<td>0.94</td>
</tr>
<tr>
<td>Gender Diversity</td>
<td>0.93</td>
<td>0.28</td>
</tr>
<tr>
<td>Knowledge of Access</td>
<td>0.89</td>
<td>0.26</td>
</tr>
<tr>
<td>Frequency of Emails</td>
<td>0.90</td>
<td>0.40</td>
</tr>
<tr>
<td>Frequency of Calls</td>
<td>0.89</td>
<td>0.26</td>
</tr>
<tr>
<td>Frequency of Meetings</td>
<td>0.90</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Table 3. Descriptive Statistics and Aggregation Analysis for All Variables

**Construct Validity**

This study involved two multi-item constructs: team cognition and team performance. The validity of the two constructs was assessed in terms of their internal consistency of measurement, convergent validity, and discriminant validity.

Table 4 presents the Cronbach alpha levels of the measured constructs at both individual level and team level. The Cronbach alpha levels are all greater than the commonly-used 0.70 level, demonstrating internal consistency of measurement.

The analysis of the convergent and discriminant validity of the two multi-item constructs was conducted using a correlation-based procedure suggested by Gefen and Straub (2005). Table 4 calculated the correlation coefficients between measurement items and their assigned variables. Gefen and Straub argued that to demonstrate both convergent and discriminant validities, loadings of measurement items on their assigned variables (marked in bold in Table 4) should be larger in magnitude than any other loading. Table 4 presented the expected pattern, providing evidence of construct validity.
Variables

<table>
<thead>
<tr>
<th>Labels</th>
<th>Items</th>
<th>TC</th>
<th>TP</th>
<th>E</th>
<th>C</th>
<th>M</th>
<th>T</th>
<th>G</th>
<th>K</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td>Team Cognition – Do you agree with the following statements? The team had a good &quot;map&quot; of each other's talents and skills.</td>
<td>0.87</td>
<td>0.59</td>
<td>0.14</td>
<td>0.3</td>
<td>0.39</td>
<td>-0.22</td>
<td>0.05</td>
<td>-0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>EL01</td>
<td>Team members were assigned to tasks commensurate with their task-relevant knowledge and skill.</td>
<td>0.86</td>
<td>0.60</td>
<td>0.18</td>
<td>0.28</td>
<td>0.35</td>
<td>-0.19</td>
<td>0.05</td>
<td>0.01</td>
<td>-0.02</td>
</tr>
<tr>
<td>EL02</td>
<td>Team members knew what task-related skills and knowledge they each possess.</td>
<td>0.88</td>
<td>0.61</td>
<td>0.12</td>
<td>0.31</td>
<td>0.43</td>
<td>-0.23</td>
<td>0.08</td>
<td>-0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>EL03</td>
<td>Team members knew who on the team has specialized skills and knowledge that is relevant to their work.</td>
<td>0.87</td>
<td>0.60</td>
<td>0.18</td>
<td>0.29</td>
<td>0.33</td>
<td>-0.21</td>
<td>0.06</td>
<td>0.09</td>
<td>-0.03</td>
</tr>
<tr>
<td>TU01</td>
<td>Team members had a common understanding of the application domain that the system was to support.</td>
<td>0.84</td>
<td>0.58</td>
<td>0.24</td>
<td>0.28</td>
<td>0.33</td>
<td>-0.17</td>
<td>0.14</td>
<td>0.16</td>
<td>0.09</td>
</tr>
<tr>
<td>TU02</td>
<td>Team members had a common understanding of the technologies used in the development process.</td>
<td>0.82</td>
<td>0.59</td>
<td>0.21</td>
<td>0.26</td>
<td>0.33</td>
<td>-0.13</td>
<td>0.14</td>
<td>0.09</td>
<td>0.16</td>
</tr>
<tr>
<td>TU03</td>
<td>Team members had a common understanding of the project development procedures. Overall, team members shared their visions of the project.</td>
<td>0.82</td>
<td>0.55</td>
<td>0.16</td>
<td>0.21</td>
<td>0.26</td>
<td>-0.14</td>
<td>0.11</td>
<td>0.01</td>
<td>0.09</td>
</tr>
<tr>
<td>TU04</td>
<td>Overall, team members shared their visions of the project.</td>
<td>0.75</td>
<td>0.58</td>
<td>0.07</td>
<td>0.25</td>
<td>0.36</td>
<td>-0.23</td>
<td>0.04</td>
<td>0.08</td>
<td>0.01</td>
</tr>
<tr>
<td>TP01</td>
<td>Team Performance - Please evaluate the performance of your project team in terms of: the amount of work the team produced.</td>
<td>0.62</td>
<td>0.88</td>
<td>0.17</td>
<td>0.23</td>
<td>0.31</td>
<td>-0.11</td>
<td>0.12</td>
<td>0.06</td>
<td>0.08</td>
</tr>
<tr>
<td>TP02</td>
<td>the efficiency of team operations.</td>
<td>0.62</td>
<td>0.89</td>
<td>0.11</td>
<td>0.13</td>
<td>0.22</td>
<td>-0.14</td>
<td>0.11</td>
<td>0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>TP03</td>
<td>the team's adherence to the schedule.</td>
<td>0.59</td>
<td>0.86</td>
<td>0.06</td>
<td>0.21</td>
<td>0.3</td>
<td>-0.17</td>
<td>0.18</td>
<td>0.09</td>
<td>0.02</td>
</tr>
<tr>
<td>TP04</td>
<td>the quality of work the team produced.</td>
<td>0.65</td>
<td>0.89</td>
<td>0.12</td>
<td>0.27</td>
<td>0.27</td>
<td>-0.10</td>
<td>0.13</td>
<td>0.22</td>
<td>0.09</td>
</tr>
<tr>
<td>TP05</td>
<td>the effectiveness of the team's interactions with people outside the team.</td>
<td>0.54</td>
<td>0.77</td>
<td>0.08</td>
<td>0.23</td>
<td>0.34</td>
<td>-0.11</td>
<td>0.11</td>
<td>0.01</td>
<td>0.22</td>
</tr>
<tr>
<td>E</td>
<td>Communication Frequency - Regarding communications between you and other members during the past ONE week, how many emails you have sent to your group members?</td>
<td>0.19</td>
<td>0.12</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>how many times you have called your group members?</td>
<td>0.34</td>
<td>0.26</td>
<td>0.37</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>how many times you and your group members have met?</td>
<td>0.42</td>
<td>0.34</td>
<td>0.39</td>
<td>0.62</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>Team size - an objective measure</td>
<td>-0.23</td>
<td>-0.15</td>
<td>0.07</td>
<td>-0.02</td>
<td>-0.10</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Gender diversity - an objective measure</td>
<td>0.10</td>
<td>0.15</td>
<td>0.10</td>
<td>-0.08</td>
<td>-0.08</td>
<td>0.05</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>I am knowledgeable and skillful of Access.</td>
<td>0.05</td>
<td>0.11</td>
<td>0.12</td>
<td>0.06</td>
<td>0.10</td>
<td>0.17</td>
<td>0.22</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>An objective measurement</td>
<td>0.31</td>
<td>0.23</td>
<td>0.28</td>
<td>0.18</td>
<td>0.33</td>
<td>-0.01</td>
<td>0.00</td>
<td>-0.02</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: N=276

Table 4. Correlation Analysis of Measurement Items

Hypotheses Testing

Analysis was conducted on the team-level dataset. To test the moderating effect of time that was explicitly incorporated in the time model, I selected multilevel-models-for-change approach as the testing method. The multilevel models for change formalizes time in a model as a variable so that its effects can be concluded from the resulting statistics (Singer and Willett 2003). More specifically, I tested the hypothesis using the following 2-level model:

Level-1: \[ Y_{ij} = \pi_{i0} + \pi_{i1}T_i + \pi_{i2}G_i + \pi_{i3}K_i + \pi_{i4}Time_{ij} + \varepsilon_{ij} \]

Level-2: \[ \pi_{i0} = \gamma_{00} + \gamma_{01}E_{ij} + \gamma_{02}C_{ij} + \gamma_{03}M_{ij} + \xi_{i0} \]
\[ \pi_{i1} = \gamma_{10} + \gamma_{11}E_{ij} + \gamma_{12}C_{ij} + \gamma_{13}M_{ij} + \xi_{i1} \]
Where:

\[ Y_{ij} : \text{the dependent variable (team performance) measured for team } i \text{ at time } j \]

\[ G_i : \text{gender diversity of team } i \]

\[ T_i : \text{team size of team } i \]

\[ K_i : \text{the average acclaimed knowledge of team } i \]

\[ E_{ij} : \text{the number of emails measured for team } i \text{ at time } j \]

\[ C_{ij} : \text{the number of calls measured for team } i \text{ at time } j \]

\[ M_{ij} : \text{the number of meetings measured for team } i \text{ at time } j \]

\[ \varepsilon_{ij}, \xi_{0i}, \text{ and } \xi_{1i} : \text{residuals at cross-team and within-team levels} \]

The level-1 sub-model formalized predictive factors at between-team level. The effects of these factors (e.g., the three control variables) on team performance were assumed not to be affected by time but the characteristics of a particular team; the level-2 sub-model formalized predictive factors at within-team level, assuming their effects were not only determined by a team’s special behavior pattern (i.e., the frequency of using the three communication modes) but also the time at which these behaviors were performed. The two levels were methodologically distinguished by their associated residuals, which indicated the extent to which between-team and within-team variances were explained by the model. By substituting for \( \pi_{0i} \) and \( \pi_{1i} \) from the level-2 sub-model into the level-1 sub-model, a full or composite multilevel model for change was arrived as described below:

\[ Y_{ij} = \gamma_{00} + \pi_0 T_i + \pi_2 G_i + \pi_3 K_i + \gamma_{03} M_{ij} + \gamma_{02} C_{ij} + \gamma_{01} E_{ij} \times \text{Time}_{ij} + \gamma_{10} M_{ij} \times \text{Time}_{ij} + \gamma_{11} C_{ij} \times \text{Time}_{ij} + \gamma_{12} E_{ij} \times \text{Time}_{ij} + (\xi_{0i} + \xi_{1i} \text{Time}_{ij} + \varepsilon_{ij}) \]

Note that the residual of the composite model (in parentheses) has an occasion-dependent component - \( \xi_{1i} \text{Time}_{ij} \) - the value of which, although unexplained by the model, is dependent on the time of measurement. The mathematical form of the composite residual reveals two common properties of occasion-specific residuals: autocorrelation and heteroscedasticity. Autocorrelation means that the residuals are correlated with each other across repeated occasions. Heteroscedasticity refers to that the residuals having unequal variances across occasions of measurement. These conditions require special treatment in model estimation. In this study, we use Full Maximum Likelihood (FML) to estimate parameters (including both regression coefficients and variance components). FML computes goodness-of-fit statistics that describe the fit of the entire model. Under FML, the goodness-of-fit statistics describes how a model fits with the sample data (Singer and Willett 2003, p. 87-90).

To attain a fair comparison among the three proposed models, FML estimation was also applied to the test of the linear model and the team cognition model, although the two models did not formalize factors at multiple levels. The testing results (path coefficients and associated significance levels) were identical to that of using classical regression analysis with least squares estimation.

The sample size of 276 data points is adequate for multilevel models for change (For a general multilevel model, Snijders and Bosker (1999) considered samples of 30 or more to be sufficient). The models were estimated using SPSS Version 14.0. To analyze models on their prediction powers and model fits, I also tested a baseline model that predicts a team’s performance based on the three control variables, a full model that includes all factors and moderating effects, and an optimal model that emerged by dropping insignificant variables. The results are reported in Table 5.

<table>
<thead>
<tr>
<th></th>
<th>Baseline Model</th>
<th>Linear Model</th>
<th>Time Model</th>
<th>Team Cognition Model</th>
<th>Full Model</th>
<th>Optimal Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>4.199***</td>
<td>3.849***</td>
<td>3.890***</td>
<td>4.012***</td>
<td>3.778***</td>
<td>3.954***</td>
</tr>
<tr>
<td>Team Size</td>
<td>-0.084</td>
<td>-0.064</td>
<td>-0.052</td>
<td>-0.005</td>
<td>0.023</td>
<td></td>
</tr>
</tbody>
</table>
Gender Diversity  0.185*  0.197*  0.209*  0.101  0.092
Knowledge of Access  0.020  0.004  0.021  0.02  0.018
Emails  0.008 -0.081** -0.347*** -0.276*** -0.271**
Calls  0.027†  0.096***  0.182  0.138  0.047*
Meetings  0.084*** -0.031 -0.867*** -0.859*** -0.753***
Time -0.001  0.054  0.051
Time X Emails  0.026**  0.014†  0.014**
Time X Calls -0.029*** -0.014† -0.016**
Time X Meetings  0.039* -0.004
Team Cognition X Emails  0.081***  0.053*  0.052*
Team Cognition X Calls -0.04 -0.022
Team Cognition X Meetings  0.212***  0.212***  0.184***
Residuals  0.116  0.102  0.069  0.082  0.067  0.067
Pseudo $R^2$  12.07%  40.52%  29.31%  42.24%  42.24%
-2 Log Likelihood 264.79 236.53 220.84 180.15 155.82 159.37
Akaikes Information Criterion (AIC) 282.79 254.53 250.84 204.15 191.82 185.37
Hurvich and Tsais Criterion (AICC) 283.47 255.20 252.69 204.15 191.82 185.37

Note: † $p<0.10$  *$p<0.05$  **$p<0.01$  ***$p<0.001$(two-tailed)
Coefficients are unstandardized
N = 276

Table 5. Analysis of Communication Effects – The Comparison of Models

Model evaluation was based on deviance statistics (including -2 Log Likelihood, AIC, and BIC. Smaller statistics indicate a better model fit), and Pseudo $R^2$. Pseudo $R^2$'s calculated the percentage of reduced residuals against the residuals of the unconditional model, which used sample mean as the only parameter for estimation. Thus, pseudo $R^2$ statistics should be interpreted as the proportional reduction in residual variance (Singer and Willett 2003, p.102-103).

As indicated in the Table 5, the time model explained the most variance of team performance among the three proposed models, with a pseudo $R^2$ of 40.52%. However, deviance statistics of the time model were higher than that of the team cognition model, suggesting that the team cognition model had certain merit regarding model fit. Of the three proposed models, the linear model of communication presented the lowest prediction power on team performance with the poorest model fit. This is in conformation to a general conclusion that linear model is overly simplified for assessing communication effects (Patrashkova-Volzdoska et al., 2003).

Close examination of variable coefficients and their associated significance levels suggests that:

H1 and its sub-hypotheses were weakly supported by the data. Only meeting frequency presented a positive and significant effect on team performance;

H2 – the moderating effect of time - was much supported by the data. Interaction statistics revealed that the effects of email frequency and meeting frequency increased over time as hypothesized, thus supporting hypotheses H2a and H2c. Contrary to the hypothesis of H2b, the effect of call frequency was found to decrease over time.

H3 – the moderating effect of team cognition – was much supported by the data. Interaction statistics revealed that email frequency and meeting frequency presented increasing effects (positive and significant) when team cognition evolved to high levels, lending support to hypotheses H3a and H3c; however, H3c of call frequency was not supported by the data, with its main effect and its interaction with team cognition failed to conclude significance.

A full model was calculated by including all the proposed factors and moderating effects. An optimal model emerged by removing significant variables and dropping insignificant ones. The optimal model presented a higher prediction power (with a Pseudo $R^2$ of 42.24%) and a better model fit (with lower model-fit statistics) than that of other models. In addition, the effects of the three control variables were not significant in the full model and were removed from the optimal model.

**SUMMARY AND DISCUSSIONS**

This study investigated the changing effects of communication on team performance during the software development process. A longitudinal study was conducted in 73 student software development teams and multi-level model of change was applied to analyze the data collected at different time points. The results suggested that:
1. The linear model of communication (H1 and its sub-hypotheses) did not explain team performance well;
2. The time model (H2 and its sub-hypotheses) and the team cognition model (H3 and its sub-hypotheses) predicted team performance well with email efficiency and meeting efficiency. However, the hypothesized effects of call frequency did not receive support from the data in both models.

The results provide evidence that communication effects are dynamic and contingent on team progress. A close examination of the testing results (Table 5) reveals that both the time model and the team cognition model have merits on predicting team performance. Because team cognition evolves with time (He et al., 2007; also, the sampled teams showed a correlation of $r=0.31, p<0.001$), the two models are not contradictory to but complementary with each other for explaining communication effects on team performance. Indeed, the optimal model suggested combining the two models to better predict team performance. Dynamic effects of communication can be illustrated by an estimation based on the concluded statistics in the full model of Table 5. Assuming three levels of team cognition of low (=3.5), medium (=4), and high (=4.5) and the four investigated time stages, the expected effects of communication are presented in Table 6.

<table>
<thead>
<tr>
<th>Levels of Team Cognition</th>
<th>Low (=3.5)</th>
<th>Medium (=4)</th>
<th>High (=4.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>-0.077</td>
<td>-0.051</td>
<td>-0.024</td>
</tr>
<tr>
<td>Stage</td>
<td>-0.064</td>
<td>-0.037</td>
<td>-0.011</td>
</tr>
<tr>
<td></td>
<td>-0.050</td>
<td>-0.024</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>-0.037</td>
<td>-0.010</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Table 6a. Email Effects

<table>
<thead>
<tr>
<th>Levels of Team Cognition</th>
<th>Low (=3.5)</th>
<th>Medium (=4)</th>
<th>High (=4.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>0.047</td>
<td>0.036</td>
<td>0.025</td>
</tr>
<tr>
<td>Stage</td>
<td>0.033</td>
<td>0.022</td>
<td>0.011</td>
</tr>
<tr>
<td></td>
<td>0.019</td>
<td>0.008</td>
<td>-0.003</td>
</tr>
<tr>
<td></td>
<td>0.005</td>
<td>-0.006</td>
<td>-0.017</td>
</tr>
</tbody>
</table>

Table 6b. Telephone Call Effects

<table>
<thead>
<tr>
<th>Levels of Team Cognition</th>
<th>Low (=3.5)</th>
<th>Medium (=4)</th>
<th>High (=4.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>-0.121</td>
<td>-0.015</td>
<td>0.091</td>
</tr>
<tr>
<td>Stage</td>
<td>-0.125</td>
<td>-0.019</td>
<td>0.087</td>
</tr>
<tr>
<td></td>
<td>-0.129</td>
<td>-0.023</td>
<td>0.083</td>
</tr>
<tr>
<td></td>
<td>-0.133</td>
<td>-0.027</td>
<td>0.079</td>
</tr>
</tbody>
</table>

Table 6c. Meeting Effects

Note: Calculation is based on coefficients of the full model from Table 5. Estimated effects are unstandardized.

Table 6. Total Effects of Different Communication Methods on Team Performance

The results demonstrate that email communication may be beneficial to team performance over time and the evolution of team cognition (Table 6a), given that team cognition will evolve with team progress. However, if team cognition remains at low levels, frequent email communication is unlikely to increase the chance of team success. The contingency on team cognition levels is most salient for meetings (Table 6c), whose effect on team performance is not sensitive to time (small and insignificant change over time). This is not surprising in that holding a meeting requires significant cognitive resources form team members. Thus, even under time pressure (e.g., time stage of 4), meeting intensively is unlikely to lead to quality performance if team members do not share their understandings of the project as well as one another’s knowledge and expertise.

As for telephone calls, the results reveal a decreasing effect on team performance over time (Table 6b). A temporary explanation could be that the sampled students tended to use telephone calls for scheduling and coordinating individual assignments rather than working out problems; thus, when the deadline was approaching, telephone calls became less effective for teams to deliver products to meet a pre-determined rigorous schedule. To further investigate this issue, I sent a following-up message to all participated students three weeks after the completion of the project, asking them to rate the extent of using the three communication methods for task scheduling and coordination needs during the software development process on a 1-5 scale ranging from little (1) to much (5). 87 students responded to this message. The use of
telephone calls was rated higher (mean = 4.17, standard deviation = 0.88) than emails (mean = 3.72, standard deviation = 1.24) and meetings (mean = 4.10, standard deviation = 0.76). Paired-T test demonstrated a significant difference between telephone calls and emails (T=3.03, p<0.01) and an ignorable difference between telephone calls and meetings (T=0.55, p>0.50). Further research is needed to clarify this issue.

As with all empirical work, this study is subject to limitations. First, the use of student subjects raises the possibility that findings may not accurately reflect the behavior of software project teams working in a business organization. Many other software development studies (e.g., Levesque et al. 2001) share this characteristic, and there is evidence that students are good proxies for “real-world” people in many contexts (King and He 2006). Further studies of team cognition "in the rough" are needed to better understand how the factors considered in this study ultimately play out in the other settings.

In addition, because all teams were working on similar projects with the same technology (Microsoft Access Databases), it was not possible to examine the role that task and technology characteristics might play in the formation of team cognition. Additional studies which consider a range of technologies and tasks would provide useful insight into the role of these factors in this process.

REFERENCES


